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Growth characteristics of multipurpose tree species, crop productivity and soil properties in agroforestry systems under subtropical humid climate in India

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Abstract: Multipurpose tree species (MPTs) were studied in an agroforestry arboretum under subtropical humid climate in Northeast India. Out of 12 MPTs planted under agroforestry systems, *Acacia auriculiformis* in spacing of 2 m × 2 m (2500 stems·hm^{-2}) could have the potentiality to meet the timber/fuelwood requirement due to its high wood production of 635 m^3·hm^{-2} with mean annual increment (MAI) of 2.54×10^{-2}· m^3·tree^1·a^{-1} in a short rotation period of 10 years. Thus, *A. auriculiformis* is a short rotation forest tree species suitable to grow in subtropical humid climate. On the other hand, at 16 years of age, *Eucalyptus hybrid* and *Michelia champaca* in spacing of 3 m × 3 m (1111 stems·hm^{-2}) produced appreciably high timber volume of 315 m^3·hm^{-2} and 165 m^3·hm^{-2} with MAI of 1.77×10^{-2} m^3·tree^{-1}·a^{-1} and 0.92×10^{-2} m^3·tree^{-1}·a^{-1}, respectively. At 16 years of age, *Gmelina arborea* produced a timber volume of 147 m^3·hm^{-2} with MAI of 1.47×10^{-2} m^3·tree^{-1}·a^{-1} followed by *Samania saman* (140 m^3·hm^{-2}), *Albizzia procera* (113 m^3·hm^{-2}) and *Tectona grandis* (79 m^3·hm^{-2}) with MAI of 1.40, 1.13 and 0.78 × 10^{-2} m^3 ·tree^{-1}·a^{-1}, respectively in 4 m × 4 m spacing (625 stems·hm^{-2}). *Gliricidia maculata* and *Leucaena leucocephala* could be used as live fences around the farm boundary to supply their N-rich leaves for mulch as well as manure to crops. In agroforestry arboretum, direct seeded upland rice (*Oryza sativa* – variety, AR-11), groundnut (*Arachis hypogaea* – variety, JL-24) and sesamum (*Sesamum indicum* – variety, B-67) were grown during the initial period upto 8 years of tree establishment. Under other MPTs, there was a reduction in crop productivity as compared to open space. After 8 years of tree establishment, horti-silvi and silvi-pastoral systems were developed and pineapple (*Ananas comosus* – variety Queen), turmeric (*Curcuma longa* -variety RCT -1) and cowpea (*Vigna sinensis* – variety Pusa Barsati) as forage crop were raised. The productivity of pineapple, turmeric and cowpea was comparatively high under *Azadirachta indica*. The productivity of horticultural and forage crops in association with trees such as *G. arborea*, *A. procera*, *S. saman*, *T. grandis* and *M. champaca* of high timber value could be harnessed as viable agroforestry systems. Changes in soil properties were also monitored. Amelioration of soil acidity, increase in soil organic carbon, and enhanced humification of soil humus, high nutrient availability, low soil erodibility and high surface soil (0–15 cm) moisture availability were noted in soils under MPTs.

Keywords: Multipurpose trees; Subtropical humid climate; Growth characteristics; Timber volume; Crop productivity; Soil organic carbon; Soil humus; Nutrient availability; Soil erodibility indices; Soil moisture.

Introduction

In India (NFAP 2003), per capita forest area and biomass availability is low to the tune of about 0.08 hm^2 and 6.0 Mg as against 0.5 hm^2 and 82 Mg, respectively for developing world. The biomass and growing stock of wood in natural forests of India is 93 Mg·hm^{-2} and 47 m^3·hm^{-2} while the average figures of the developing world are 163 Mg·hm^{-2} and 113 m^3·hm^{-2}, respectively. So, Indian forestry is in a phase of dismal scenario due to heavy pressure of burgeoning human population on land, growing demand of timber, fuelwood, fodder, grazing, encroachment, shifting cultivation, urbanization, industrialization and improper land management.

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In spite of various traditional forms of agroforestry in different parts of India (Nair 1989; Tejwani 1994), recognition of trees as components of farming systems (Nair 2001) is rather limited. In north-east India, shifting cultivation which is regarded as the 1st step in transition from food gathering or hunting to food production and is believed to have originated in the Neolithic period around 7000 B.C., is still in practice (Borthakur 1977; Singh *et al.* 1981).

In India, there are more than 250 indigenous multipurpose trees which are providing multiple products and services in agroforestry systems and are of high adaptability in diverse habitats and climates as documented by Toky *et al.* (1992). The economic return of multipurpose tree species (MPTs) from the supply of fuelwood and timber is time consuming and thus crops are to be grown in the interspaces of MPTs to make the agroforestry interventions economically viable.

Generally, soils of humid tropics are of low exchangeable base, low nutrient reserves, high aluminium toxicity, low phosphorus availability, low organic matter and mild to strong soil acidity. The potential for agroforestry systems to increase nutrient stocks on infertile acid soils appears to be variable. The proposed abilities of agroforestry systems to maintain or improve soil chemical properties and organic matter and protect the soil surface are related to the processes of litter or fine root production, decom-

position and soil organic matter transformation. Loss of nutrients by leaching, erosion and runoff can be minimized by tree derived mulch, litter or foliage (Sanchez 1987; Lal 1984) and an annual crop or cover of legumes or other vegetation during the initial period of tree establishment can provide an effective soil cover to arrest soil erosion (Sanchez 1995).

Thus the present study is to record the growth parameters of multipurpose tree species (MPTs) planted in different spacing for the supply of fuel wood, fodder, timber and tree leaves for green manuring in humid sub-tropical climatic conditions. An attempt is also made to investigate the crop productivity during the initial or later stage of tree growth and monitor the changes in soil chemical properties, soil moisture and soil erodibility characteristics in soils under MPTs

Materials and methods

Experimental site

The study was conducted in the research farm of Indian Council of Agricultural Research (ICAR) Complex for North Eastern Hill Region, Tripura, India. The area is characterized by dry winters and hot summers followed by heavy rains. The mean maximum temperature ranges from 29.2 °C to 36.8 °C and the mean minimum temperature from 4.1°C to 21.4°C with average maximum and minimum temperature being 35°C and 10.5°C, respectively. It receives 2 255 mm of rainfall.

In soils (Fine, Kaolinitic, Typic Kandiudults) classified under Acrisols of upland (40–65 m above msl) toposequence, 12 multipurpose tree species (MPTs) suitable for humid subtropical region were planted in 1989 in randomized block design with 8 replications. The physico- chemical properties (Bhattacharyya *et al.* 2003) of the soil series are presented in Table 1. Soils are acidic in nature with pH (4.1 to 4.4), low organic carbon (0.2% to 0.8%) and high aluminum saturation (53% to 63%) as exchangeable cation.

Growth characteristics

General characteristics of multipurpose tree species suitable for humid subtropical climate are presented in Table 2. Growth parameters, viz., tree height, basal diameter, diameter at breast height (dbh) and bole volume were recorded (Dhanda 2004) and data for 8 and 16 years besides *Acacia auriculiformis* which was clear felled after 10 years, are reported in the text. Using diameter at breast height and height, bole volume ($1/3\pi r^2h$) was estimated, where *r* was the radius of the bole and *h* was the height of the tree. Form quotient is defined as the ratio between mid diameter and dbh (Dhanda 2004).

Table 1. Physio-chemical properties of soils (Fine, kaolinitic, Typic Kandiudults) of experimental site (Acrisols)

Depth (cm)	O.carbon (%)	pH	Mechanical analysis (%)			Exchangeable cations{ cmole (p^+) kg^{-1}}			Cation exchange capacity {cmole (p^+) kg^{-1}}	Base saturation (%)
			Sand	Silt	Clay	Ca^{2+}+Mg^{2+}+Na^++K^+	H^+	Al^{3+}		
0-12	0.8	4.1	37.0	22.1	40.9	1.2	0.6	3.5	6.6	18
12-26	0.4	4.3	33.0	23.1	43.9	1.3	1.0	3.7	7.0	20
26-46	0.3	4.4	30.4	24.7	44.9	1.3	0.5	3.6	5.9	22
46-95	0.3	4.3	28.6	24.5	46.9	1.2	0.7	3.5	5.6	20
95-162	0.2	4.4	27.6	24.4	47.9	1.4	0.8	3.9	7.0	20

Crop productivity

In agroforestry arboretum, there are three different systems, namely agri-silvi, horti-silvi and silvi-pastoral systems in association with MPTS planted at variable spacing. Under agri-silvi systems, direct seeded upland rice (*Oryza sativa* - var. AR-11), groundnut (*Arachis hypogaea* - var. JL-24) and sesamum (*Sesamum indicum* - var.B-67) were grown during the initial period up to eight years of their planting. The productivity of the annual crops recorded at harvest was pooled from the data of three cropping seasons. After 8 years, horti-silvi and silvi-pastoral systems were developed and pineapple (*Ananas comosus* - var. Queen), turmeric (*Curcuma longa* - var. RCT -1) and cowpea (*Vigna sinensis* - var. Pusa Barsati) as forage crop were raised. Pooled productivity data from horti-silvi and silvi-pastoral systems were reported. The physico –chemical assay of pineapple,viz., total soluble solids, reducing sugar, total sugar and acidity was evaluated following the methods described in AOAC (1984).

Soil analysis

Soils (0–15 cm) collected from the systems were seasonally analysed (Piper 1966; Jackson 1973) for physico –chemical properties. Dilute alkali soluble humus and humin fractions of soils were isolated, purified (Schnitzer *et al*. 1972, 1978) and analyzed for organic carbon contents and E_4/E_6 ratio (Chen *et al*. 1977). Sieved air- dried 2.5-g soil was weighed into 100-mLconical flask. To this, 20 mL of 0.1 N H_2S0_4 was added. The suspension was agitated for one hour and kept overnight. The clear acid solution was filtered and the soil was washed free of acid. To the washed soil, 0.1 N NaOH solution was added (Soil: solution 1:10), agitated (Nitrogen atmosphere) for one hour and kept overnight. The suspension was then centrifuged and washed with water till the supernatant was colorless. The alkaline soil was then washed with distilled water by centrifugation to avoid the loss of dispersed clay particles or dispersed clay –humus complexes. The alkali free soil was quantitatively transferred into 500-mL conical flask and this moist soil was dried in an oven at 40–45°C. Then the organic carbon content in the soil (soil humin carbon) was determined by wet combustion method (Wakley *et al*. 1934). Dilute alkali soluble humin carbon was obtained by subtracting soil humin carbon from the total soil organic carbon. The alkaline extract of the acid washed soil was acidified with 6 N HCl to lower the pH to 2.0 and humic acid (HA) was allowed to precipitate. After keeping overnight, the suspension was filtered and washed with acid. The washed humic acid (HA) left behind on the filter paper was dissolved by dropwise addition of 0.1 N NaOH solution and solution was collected in a beaker. The humic acid (HA) was then precipitated with 0.1 N HCl and centrifuged. It was then treated 3 times with 0.5% HCL –HF mixture for 36 h (Schnitzer *et al*. 1972), washed with distilled water and dialysed. The ion free HA was dried in a freeze dryer, powered

and stored over $CaCl_2$ in a desiccator. For measuring optical absorbances at 465 nm and 665 nm (E_4/E_6 ratio), 2 to 4 mg of humic material was dissolved in 10 mL of 0.05 N $NaHCO_3$ to maintain the resulting pH of the humic acid around 8. The absorbances of the solution with 0.05 N $NaHCO_3$ solution as reference were measured to find out the E_4 / E_6 ratio.

Table 2. Description of experimental tree species under subtropical humid climate

Forest tree species	Local name	Family	Environmental requirements	Uses
Acacia auriculiformis A. Cunn	Akashmoni	Leguminosae (Mimosoideae)	Mean annual temperature (26–40 °C), rainfall (600–2200 mm), drought tolerant, soil (deep or shallow or acidic or alkaline), altitude (sea level to 700 m or more), evergreen.	Fuel - wood, Timber-wood, Shade/ornamental tree.
Morus alba, Linn	Tut	Moraceae	Mean Annual temperature (10 – 43 °C), rainfall (400–4500 mm), soil (fertile with ph 6.0–7.5), altitude (sea level to 1200 m), deciduous.	Rearing silk-worms, fuel wood, timber wood, fodder.
Leucaena leucocephala, Lank	Subabul	Mimosoideae	Temperature (Tolerance upto 45°C and susceptible to frost), rainfall (600–1700 mm), soil (neutral to slightly alkaline), altitude (sea level to 1000 m), evergreen to deciduous.	Fodder, fuel wood, small timber, leaf as soil mulch.
Dalbergia sissoo, Roxb	Shisam	Papilionaceae	Temperature (6 to 39°C), rainfall (750—4000 mm), soil (well drained with moisture supply), altitude (below 900 m above mean sea level), deciduous.	Paper pulp, fuel wood, timber wood, fodder, lubricant.
Gliricidia maculata, H.B. & K	Gliricidia	Papilionaceae	Temperature (20 –38°C), Rainfall (800–2400 mm), soil (well drained marginal fertility), altitude (sea level to 700 m), deciduous.	Green manure, fencing, fuel wood, fodder.
Azadirachta indica, A. Juss	Nim	*Meliceae*	Temperature (5 to 45°C), rainfall (450–1150 mm), soil (deep or shallow with ph 5.0 to 6.2), altitude (650 to 1000 m), usually evergreen.	Medicinal or insecticidal properties, fodder, fuel wood, small timber.
Michelia champaca, Linn	Champa	Magloniaceae	Temperature (15 to 40°C), rainfall (1200 to 2200 mm), soil (fertile alluvial or red), altitude (200 to 1200 m), evergreen.	Ornamental, fuel wood, timber, fodder.
Eucalyptus hybrid, L. Herit	Safeda	Myrtaceae	Temperature (below 0 to 47 °C), rainfall (500 – over 2000 mm), soil (deep fertile well drained), altitude (sea level to 1000 m)	Pulpwood, fuel wood, charcoal, timber wood, leaf oil.
Tectona grandis, Linn	Teak	Verbenaceae	Temperature (15 to 35°C), rainfall (700 – 2400 mm), soil (well drained fertile uplands), altitude (sea level to 600 m)	Timber wood, fuel wood, wind break.
Gmelina arborea, Linn	Gamahar	Verbenaceae	Temperature (15 to 35°C), Rainfall (700 – 2400 mm), Soil (well drained fertile uplands), Altitude (sea level to 600 m)	Timber wood, fuel wood.
*Samania saman,*Jacq	Raintree	Mimosaceae	Temperature (15 to 35 °C), rainfall (700 – 2400 mm), soil (well drained fertile uplands), altitude (sea level to 600 m)	Timber wood, fuel wood, fodder.
Albizzia procera, Linn	White Siris	Mimosaceae	Temperature (15 to 35°C), rainfall (700 – 2400 mm), soil (well drained fertile uplands), altitude (sea level to 600 m)	Timber wood, fuel wood, fodder.

Contents of both macro and micro nutrient availability were also estimated. Various erodibility indices, (Middelton 1930; Baver *et al*. 1978) viz., clay ratio [(sand + silt)/clay], silt/clay ratio, suspension per cent [(silt + clay) suspended in pure water / total content of (silt + clay)], clay - available water ratio, dispersion [suspension per cent /total content of (silt + clay)] and erosion (dispersion / clay -available water) ratios were estimated (Datta *et al*. 1990). Soil moisture contents in soils under MPTS were estimated gravimetrically (Piper 1966).

Results

Growth characteristics

Tree height, basal diameter, diameter at breast height and bole volume recorded upto 8 and 16 years for multipurpose tree species are presented in Table 3.After 10 years of tree planting, *A. auriculiformis* attained the height of (18.10±3.35) m. The maximum height recorded at 16 years of age was (19.40±4.12) m in *Eucalyptus hybrid* followed by *G. arborea* ((15.20±1.29) m), *S. saman* ((14.02±1.27) m), *A. procera* ((13.90±1.74) m), *T. grandis* ((13.40±1.28) m), *M. champaca* ((13.30±3.31) m) and *D. sissoo* ((10.90±2.30) m) thus showing 44% to 93 % increase in height during 9–16 years of age.

The other tree/shrub species, viz., *M. alba*, *L. leucocephala, G. maculata, A. indica* were only of 8.63 m to 12.10 m in height at 16 years of age. At 8 years of age, basal diameter of MPTs underwent a variation from (7.15±2.15) m to (25.0±4.21) m with the lowest and highest in *L. leucocephala* and *A. auriculiformis*, respectively. On the other hand, at 16 years of age, *Eucalyptus hybrid* showed the maximum basal diameter of (31.73 ± 2.28) m. The lowest basal diameter at 16 years of age was noted in *G. maculata* ((15.70 ± 2.20) m) with 61% increase over that at 8 years. *A. auriculiformis* at 8 years showed the maximum diameter at breast height of (19.12±2.21) m which was raised to (23.15±2.24) m at 10 years. But *S. saman* could produce the maximum d.b.h. of (24.41±2.21) m at 16 years thus showing 67.5% increase over that at 8 years. The dbh of *M. alba* at 16 years was the lowest ((11.08±1.27) m) with 78.1% increase over that at 8 years. In *A. auriculiformis*, the bole volume was the maximum ((13.82±1.28) $\times 10^{-2}$ $m^3 \cdot tree^{-1}$) at 8 years and thereafter, it was raised to (25.43±1.58) $\times$ 10^{-2} $m^3 \cdot tree^{-1}$ at 10 years. At 16 years, bole volume was the maximum ((28.36±0.87) $\times$ 10^{-2} $m^3 \cdot tree^{-1}$) in *E. hybrid* followed by *G. arborea* ((23.44±0.92) $\times$ 10^{-2} $m^3 \cdot tree^{-1}$), *S. saman* ((22.42 ± 0.52) $\times$ 10^{-2} $m^3 \cdot tree^{-1}$), *A. procera* ((18.08±0.29) $\times 10^{-2}\cdot$ $m^3 \cdot tree^{-1}$), *M. champaca* ((14.82±0.98) $\times 10^{-2}$ $m^3 \cdot tree^{-1}$) and *T. grandis* ((12.56±0.82) $\times$ 10^{-2} $m^3 \cdot tree^{-1}$). After 16 years of growth, timber volume and form quotient for the main timber producing tree species were calculated and presented in Fig. 1.

Table 3. Growth characteristics of multipurpose tree species under subtropical humid climate (means ± SD)

Tree species	Density	Height (m)		Basal diameter (cm)		Diameter at breast height (cm)		Bole volume$\times10^{-2}$ ($m^3\cdot tree^{-1}$)	
		Age (yrs)		Age (yrs)		Age (yrs)		Age (yrs)	
		0–8	9–16	0–8	9–16	0–8	9–16	0–8	9–16
Acacia auriculiformis	2500 stems·hm^{-2}	14.43 ±2.39	18.10* ±3.35	25.0 ± 4.21	29.54* ± 4.25	19.12 ±2.21	23.15* ± 2.24	13.82 ± 1.28	25.43* ±1.58
Morus alba		4.02 ± 0.42	9.02 ±2.25	8.54 ± 3.54	18.79 ± 3.92	6.22 ±1.10	11.08 ± 1.27	0.41 ±0.02	2.90 ±0.51
Leucaena leucocephala		6.65 ± 1.23	12.10 ±2.54	7.17 ± 2.15	16.58 ± 3.23	5.72 ±1.12	15.74 ± 2.23	0.57 ± 0.05	7.83 ±0.54
Dalbergia sissoo		6.46 ± 1.28	10.90 ±2.30	11.10 ± 2.14	20.09 ±2.25	8.53±1.15	16.78 ± 2.23	1.23 ±0.12	8.10 ±0.56
Gliricidia maculata	1111 stems·hm^{-2}	5.62 ± 1.24	9.90 ±1.24	9.75 ± 2.45	15.70 ± 2.20	7.60 ±1.14	13.52 ± 2.28	0.85 ±0.09	4.74 ±0.24
Azadirachta indica		5.02 ± 0.59	8.63 ±2.45	10.65 ±3.56	22.51 ±3.35	9.35 ±2.20	16.80 ± 2.20	1.15 ±0.14	6.37 ±0.29
Michelia champaca		6.89 ± 0.25	13.30 ±3.31	14.18 ± 3.29	26.72 ±2.23	10.95 ±2.24	20.63 ± 3.32	2.15 ±0.29	14.82 ± 0.98
Eucalyptus hybrid		13.46 ±1.20	19.40 ± 4.12	16.19 ± 4.78	31.73 ±2.28	13.22 ±1.13	23.64 ±3.28	6.16 ±0.80	28.36 ± 0.87
Tectona grandis	625 stems·hm^{-2}	7.79 ± 2.31	13.40 ± 1.28	13.32 ±1.27	27.13 ± 1.25	10.92 ±1.24	18.93± 2.28	2.43 ±0.24	12.56 ± 0.82
Gmelina arborea		10.02 ±1.32	15.20 ± 1.29	22.07 ± 4.28	31.25 ± 3.37	18.02 ±2.29	24.24 ±1.24	8.51 ± 0.52	23.44 ±0.92
Samania saman		7.72 ±1.50	14.02 ± 1.27	18.97 ±3.10	29.19 ±2.28	14.75 ± 1.14	24.71 ± 2.21	4.37 ±0.54	22.42 ±0.52
Albizzia procera		7.84 ± 0.54	13.90 ± 1.74	15.04± 2.20	27.98 ±3.31	13.43 ±2.27	22.26 ±3.30	3.70 ±0.82	18.08 ±0.29
CV(%)		38.31	24.44	36.8	22.25	36.26	22.40	44.21	57.76
LSD (P=0.05)		0.79	0.83	1.36	1.42	1.08	1.15	0.99	2.18

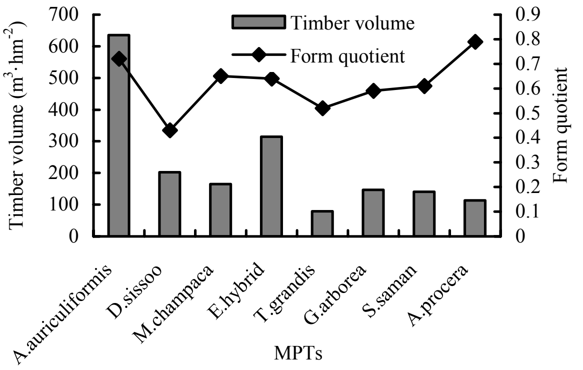

Fig. 1 Timber volume and form quotient of some timber producing tree species in agroforestry systems

Timber volume underwent a variation from 635 m^3·hm^{-2} to 78.5 m^3·hm^{-2} and the form quotient which is defined as the ratio between mid- diameter and d.b.h, varied from 0.43 to 0.79. Mean annual increment (MAI) presented in Table 4 indicated that *A. auriculiformis* after 10 years showed the value of 2.54×10^{-2} m^3·tree^{-1}·a^{-1} followed by *E. hybrid* (1.77), *G. arborea* (1.47), *S. saman* (1.40), *A. procera* (1.13) and *M. champaca* (0.92), etc. at 16 years of age. On pruning in alternate years in MPTs usually 5 years after their planting, the average fuelwood productivity varied (Table 4) from 1.97 Mg·hm^{-2} to 8.75 Mg·hm^{-2} with lowest and highest in *L. leucocephala* and *G. arborea* and, respectively.

Under the canopy of MPTs, light intensity was measured both before and after pruning. A wide variability in light intensity (10,143 to 40,149 lx) was noted with 13.5% to 53.4% light available (Fig.2) under MPTs before pruning in comparison to open space. After pruning, light intensity was adequately raised of 67.1% to 88.2% light (55,563 to 73,038 lx) available under MPTs compared to open space.

Crop productivity

Pooled data on crop productivity in three variable systems under MPTs are presented in Table 5. An inconsistent change in the productivity of field crops under agri-silvi systems continued during the initial period of 1–8 years of tree planting was noted. The productivity of direct seeded upland rice underwent a variation from 1.25 Mg·hm^{-2} to 1.45 Mg·hm^{-2} thus indicating an average decline of 19.4 per cent (Fig. 3) in productivity as compared to open space. On the other hand, productivity of groundnut pod varied from 0.31 Mg·hm^{-2} to 1.14 Mg·hm^{-2} under the canopy of MPTs. Thus, an average 40.5 % decline (Fig. 3) in groundnut productivity compared to open space was noted. The productivity of sesamum under MPTs was from 0.38 Mg·hm^{-2} to 0.74 Mg·hm^{-2} showing 30.2% decline (Fig. 3) compared to open space.

Table 4. Mean annual increment, fuelwood and light intensity available under canopy of MPTS

MPTs	Mean annual increment (MAI)	Fuelwood (Mg·hm^{-2})	Light Intensity (lx)	
			I	II
A. auriculiformis	2.54*	5.97	10,143	55,563
M. alba	0.18	2.70	13,450	58,200
L. leucocephala	0.48	1.97	21,134	70,914
D. sissoo	0.51	2.57	21,543	69,976
G. maculate	0.29	4.02	37,816	71,800
A. indica	0.38	3.29	22,893	73,038
M. champaca	0.92	3.57	23,124	72,000
E. hybrid	1.77	3.79	26,634	70,175
T. grandis	0.78	3.89	11,453	71,650
G. arborea	1.47	8.75	40,149	72,475
S. saman	1.40	6.16	22,693	70,650
A. procera	1.13	3.71	20,554	67,463
No tree		-	75,200	82,800
LSD (P=0.05)	0.08	0.85	1524	1828

Notes: * 10 years, I--Before pruning; II-- After pruning; Mean annual increment (MAI) { × 10^{-2} m^3·tree^{-1}·a^{-1} } at 16 years

In horti –silvi culture system, pineapple and turmeric were grown and the productivity (Table 5) of pineapple underwent a variation from 2.34 Mg·hm^{-2} to 9.29 Mg·hm^{-2} with a mean value of 6.40 Mg·hm^{-2} thus showing nearly 40% decline in fruit productivity (Fig. 3) compared to open space. The quality of pineapple produced in association with MPTs was evaluated through physico –chemical assay. The total soluble solid (Table 6) of the fruit produced under MPTs was from 14.3% to 18.2 % thus indicating 0.7% to 28.2% increase over the fruit of open space. The reducing sugar and total sugar content were found maximum (10.9% and 14.5%) in the fruit produced under the canopy of *M. champaca* and *L. leucocephala*, respectively. An increase of

21.9% and decline of 0.68% in reducing sugar and total sugar content over the fruit of open space were noted. Acidity of the fruit varied from 0.44 %to 1.08% thereby showing maximum decline of 31.3% and increase of 68.8% over the fruit of open space in pineapple grown under the canopy of *T. grandis* and *A. procera*, respectively. TSS/acidity ratio showed a variation from 15.88 to 40.45 in fruit grown under the canopy of *M. champaca* and *T. grandis*, respectively.

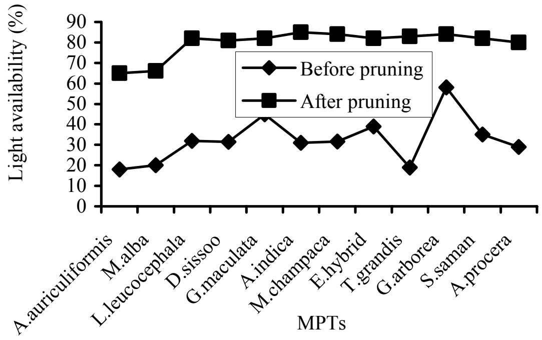

Fig. 2 Per cent light availability under MPTs compared to open space

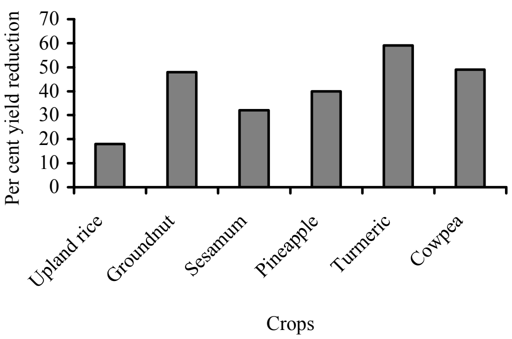

Fig. 3 Crop yield reduction under the cover of MPTs

Table 5. Crop productivity ($Mg{\cdot}hm^{-2}$) in agroforestry systems

MPTs	Agri-silvi System[a]			Horti-silvi System[b]		Silvi-pastoral System[b]
	Upland Rice	Groundnut	Sesamum	Pineapple	Turmeric	Cowpea (forage yield)
A. auriculiformis	1.32	0.31	0.54	2.34	1.87	6.27
M. alba	1.25	0.98	0.43	4.50	2.25	4.15
L. leucocephala	1.33	1.05	0.72	7.72	2.21	8.59
D. sissoo	1.36	1.02	0.58	7.10	2.14	3.29
G. maculata	1.37	0.95	0.38	3.76	2.42	6.98
A. indica	1.33	1.03	0.58	9.29	4..17	7.09
M. champaca	1.45	1.14	0.38	3.81	2.21	9.94
E. hybrid	1.35	1.03	0.64	5.27	2.77	3.33
T. grandis	1.38	1.07	0.52	6.80	1.74	1.87
G. arborea	1.33	1.09	0.67	7.25	2.55	7.09
S. saman	1.39	1.08	0.63	8.67	2.11	3.84
A. procera	1.35	1.07	0.74	6.66	2.08	3.16
Mean	1.35	0.98	0.57	6.09	2.38	5.47
No tree cover	1.65	1.83	0.85	10.09	5.63	10.52
LSD (P=0.05)	0.08	0.25	0.38	1.24	1.51	1.84

Notes: [a]---Average of 3 cropping seasons during 0–8 years; [b]---Average of 3 cropping seasons during 9–16 years.

Productivity of turmeric in association with tree species varied from 1.87 $Mg{\cdot}hm^{-2}$ to 4.17 $Mg{\cdot}hm^{-2}$ with 50.8% reduction (Fig. 3) in rhizome yield compared to that in open space. In silvi-pastoral system, cowpea was grown and forage yield with a variation from 1.87 $Mg{\cdot}hm^{-2}$ to 9.94 $Mg{\cdot}hm^{-2}$ was recorded. An average yield of cowpea was (5.86 ±0.74) $Mg{\cdot}hm^{-2}$ thus indicating nearly 50% reduction in productivity compared to that in the area without any tree cover

Table 6. Physico –chemical assay[a] of pineapple

MPTs	TSS (%)	Reducing sugar (%)	Total sugar (%)	Acidity (%)	TSS/acidity ratio
A. auriculiformis	17.6	8.90	12.70	0.96	18.33
M. alba	14.3	7.50	14.20	0.89	16.07
L. leucocephala	15.2	9.20	14.50	0.70	21.71
D. sissoo	16.2	9.50	13.76	0.83	19.52
G. maculata	14.4	8.19	12.52	0.57	25.26
A. indica	17.1	8.34	14.30	0.51	33.53
M. champaca	16.2	10.90	13.97	1.02	15.88
E. hybrid	16.0	8.98	13.98	0.76	21.05
T. grandis	17.8	9.30	14.10	0.44	40.45
G. arborea	17.9	7.34	11.95	0.89	20.11
S. saman	17.0	9.70	12.89	0.83	20.48
A. procera	18.2	9.81	14.12	1.08	16.81
Mean	16.3	8.96	13.60	0.77	22.40
No tree	14.2	8.94	14.60	0.64	20.19
LSD(P=0.05)	1.25	0.34	0.41	0.07	1.35

Notes: [a]Average values from 9-16 years.

Soil properties

The average values of soil physico –chemical properties of surface soil (0–15 cm) under MPTs during 4–16 years are presented in Table 7. Soil pH was found to vary from 4.1 to 6.0. *A. indica* showed the maximum rise in soil pH (1.6 unit) while *G. maculata* showed a decline in soil pH (0.3 unit) as compared with open space (No tree). Exchangeable acidity ($H^{+}+Al^{+3}$) estimated in the surface soil (0–15 cm) was found to vary from 3.30 to 6.60 c mol(p^{+})kg^{-1}. The lowest exchangeable acidity was recorded in soils under *A. indica* and the highest in soil under *L. leucocephala*. Water holding capacity showed an increase from 28.94% to 34.27% in *A. indica*. Similar rise in water holding capacity was also recorded in soils under *A. auriculiformis* and *D. sissoo* but other MPTs showed a declining trend as compared to that in the soils of open space. Mechanical analysis showed that sand, silt and clay in soils under MPTs varied from 45.5% to 62.8%, 5.40% to 19.40% and 17.8% to 42.8%, respectively and soils of open space had 59.9% sand, 3.93% silt and 36.2% clay.

Soil organic carbon pool (Table 8) was estimated in surface soils (0–15 cm) under MPTs. This showed a concomitant rise in SOC in soils under MPTs and a subsequent decline in soils of open space over 4–16 years. Maximum rise in SOC was noticed in soils of *A. indica* (28.6 $Mg{\cdot}hm^{-2}$) followed by *A. aurculiformisi* (21.9 $Mg{\cdot}hm^{-2}$), *G. arborea* (21.8 $Mg{\cdot}hm^{-2}$), *M. champaca* (16.7 $Mg{\cdot}hm^{-2}$), etc. The minimum rise in SOC was noted in soils under *T. grandis*. So an increase of SOC was noted from 3.8 $Mg{\cdot}hm^{-2}$ in soils of open space to 19.5 $Mg{\cdot}hm^{-2}$ in that under MPTs after 16 years.

Dilute alkali soloube humus as well as humin fractions were also estimated and the data are presented in Table 9. The amount of humin organic carbon content was of maximum (5.35 $g{\cdot}kg^{-1}$)

in soils under *A. auriculiformis,* followed by *G. arborea* (4.47g·kg^{-1}). Soils under *A. indica,* though showed a high value of organic carbon, contained low humin carbon (2.13 g·kg^{-1}). This low humin carbon in soils under *A. indica* showed only 7.6% of organic matter humification. On the other hand, dilute alkali soluble humic carbon underwent a variation from 7.4 to 26.5 g·kg^{-1}. This indicated accumulation of alkali soluble humus in high amount in soils under *A. indica* (26.5 g·kg^{-1}) followed by *G. arborea* (17.3 g·kg^{-1}), *M. champaca* (15.9 g·kg^{-1}), *E. hybrid* (15.1 g·kg^{-1}) etc. This showed an increase in humus accumulation in soils under MPTs compared to open space (7.4 g·kg^{-1}).

Table 7. Effect of MPTs on soil physico-chemical properties[a]

MPTs	Soil pH	Exchangeable acidity [c mol (p$^+$) kg^{-1}]	Water holding capacity (%)	Mechanical analysis (%)		
				Sand	Silt	Clay
A. auriculiformis	5.3	4.29	31.17	55.8	10.0	34.2
M. alba	4.7	4.29	26.50	59.9	15.20	24.3
L. leucocephala	4.6	6.60	25.90	60.8	20.3	18.9
D. sissoo	5.4	4.29	29.22	57.8	9.80	32.4
G. maculata	4.1	5.61	25.62	51.0	9.70	39.3
A. indica	6.0	3.30	34.27	60.6	9.61	29.8
M. champaca	4.1	4.62	40.82	60.8	17.40	21.9
E. hybrid	4.7	4.95	25.98	58.3	11.90	29.8
T. grandis	5.2	5.94	27.14	57.2	5.40	38.9
G. arborea	4.8	5.94	25.57	63.6	12.62	23.2
S. saman	5.0	4.29	27.82	62.8	19.40	17.8
A. procera	5.0	3.96	25.57	45.5	11.71	42.8
Open space	4.4	6.27	28.94	59.9	3.93	36.2
Mean	4.8	4.95	28.93	53.2	12.11	29.9
CV (%)	10.4	18.4	14.5	12.7	39.22	26.2
LSD (P=0.05)	0.21	0.27	2.54	2.19	5.27	4.47

Notes: [a]---Average values from 4-16 years.

The ratio of alkali soluble organic carbon and humin organic carbon (*R*) showed a variation from 3.1 to 13.2. The lower the value of the ratio, the higher would be the humification rate. So soils under *A. auriculiformis,* showing the least value (3.1) of the ratio indicated the high humification rate. On the other hand, the lower the value of inverse ratio, the lower would be the rate of humification and vise-versa. Comparatively, high value of inverse ratio in soils under *A. auriculiformis*, *L. leucocephala*, *G. arborea* indicated high humification rate. E_4/E_6 ratio of the absorbance of humic acid solution at 465 nm and 665 nm is also an index of humification. The low value of E_4/E_6 ratio indicated a high degree of humification of soil humic substances and high value indicated low degree of humification. Here, E_4/E_6 ratio was found to vary from 1.64 to 5.38, thus showing low degree of humification in soils of open space evidenced by high E_4/E_6 ratio (5.38). On the basis of E_4/E_6 ratio, it can be said that soils under the canopy of *A. auriculiformis, M.champaca*, *T. grandis*, *D. sissoo* showed low humification of the organic matter. But soils under the canopy of other MPTs showed high humification due to low value of E_4/E_6 ratio of soil humic substance. Soils of open space were of low humification due to high E_4/E_6 ratio and all other soils under MPTs indicated higher humification than soils of open space.

Available NPK and micronutrients (Fe, Mn and Zn) were estimated in soils under canopy of MPTs and the data are presented in Table 10. Available nitrogen was found varying from 370 kg·hm^{-2} to 497 kg·hm^{-2}, thus showing the medium status of nutrient availability. Soil under *A. procera, T. grandis*, *E. hybrid*, *M. alba* showed 7% to 14% increase in nutrient availability over open space. Available phosphorus (Bray P_2), on the other hand was found varying from 12.4 kg·hm^{-2} to 29.4 kg·hm^{-2}, thus showing medium to high nutrient status. High P status was noted in soils under *M. alba*, *S.saman*, *T.grandis*, *G. arborea* and *E. hybrid.* Available potassium showed a variation from 85 to 143 kg·hm^{-2}, thus showing low to medium nutrient status. Low potassium availability was noted in soils under *G. maculata*, *M. champaca*, *T.grandis* and *S. saman.* But *A. procera* showed the highest potassium availability, thus indicating 32% increase over open space. Available Fe and Mn showed a variation from 59.2 to 118.8 mg·kg^{-1} and 12.5 to 33.2 mg·kg^{-1}, respectively thus indicating high micronutrient availability in soils under MPTs. On the other hand, available Zn showed a variation from 0.34 to 0.93 mg·kg^{-1} thus indicating Zn stress in soils under MPTs planted in upland toposequence.

Table 8. Changes in SOC (Mg·hm^{-2}) over the years

MPTs	Years (a)			
	4	8	12	16
A. auriculiformis	11.1	11.9	17.9	21.9
M. alba	9.9	9.9	9.9	15.9
L. leucocephala	11.5	11.5	12.8	16.7
D. sissoo	13.1	12.5	13.1	13.9
G. maculate	13.1	13.1	13.9	14.9
A. indica	10.9	10.9	14.7	28.6
M. champaca	13.9	13.7	13.9	16.9
E. hybrid	9.9	9.9	14.9	16.1
T. grandis	11.5	11.3	11.5	12.9
G. arborea	12.2	12.2	12.8	21.8
S. saman	10.6	11.3	11.3	13.9
A. procera	13.5	13.1	13.5	14.7
Open space	11.9	11.9	11.1	9.1
Mean	11.8	11.8	13.2	16.7
CV (%)	10.8	14.3	14.9	30.7
LSD (P=0.05)	2.27	2.54	1.58	3.45

Table 9. Humus[a] in soils under MPTs

MPTs	Humin O. carbon ($g\cdot kg^{-1}$)	Alkali soluble O. carbon ($g\cdot kg^{-1}$)	Humin O. carbon (%)	Ratio of alkali soluble & Humin O. carbon (*R*)	E_4/E_6 ratio	Inverse ratio of *R*
A. auriculiformis	5.35	16.6	24.4	3.1	4.47	0.32
M. alba	2.25	13.7	14.2	6.1	3.15	0.16
L. leucocephala	2.58	14.1	15.4	5.5	3.56	0.18
D. sissoo	1.21	12.7	8.7	10.5	4.73	0.09
G. maculata	1.14	13.8	7.7	12.1	1.91	0.08
A. indica	2.13	26.5	7.6	12.4	2.37	0.08
M. champaca	1.05	15.9	6.2	15.1	5.01	0.06
E. hybrid	1.04	15.1	6.5	14.5	1.64	0.07
T. grandis	1.13	11.8	8.8	10.4	4.00	0.09
G. arborea	4.47	17.3	20.5	3.9	3.35	0.26
S. saman	1.04	12.9	7.5	12.4	1.83	0.08
A. procera	1.04	13.7	7.1	13.2	2.30	0.08
Open space	1.75	7.4	24.7	4.2	5.38	0.24
Mean	2.05	14.7	12.3	9.5	3.70	0.14
CV (%)	14.3	28.2	53.8	43.6	36.8	59.3
LSD (P=0.05)	0.21	2.54	0.51	1.14	0.26	0.05

Notes: [a]----Average values from 4–16 years

Table 10. Effect of MPTs on nutrient availability[a]

MPTs	Macronutrients ($kg\cdot hm^{-2}$)			Micronutrients ($mg\cdot kg^{-1}$)		
	N	P	K	Fe	Mn	Zn
A. auriculiformis	372	18.6	128	68.0	33.2	0.72
M. alba	466	29.4	116	65.5	10.0	0.39
L. leucocephala	404	17.0	97	62.1	16.8	0.93
D. sissoo	466	12.4	128	118.8	10.3	0.68
G. maculata	466	12.4	124	56.7	13.5	0.59
A. indica	404	15.5	100	70.1	20.0	0.36
M. champaca	372	27.9	85	84.4	13.9	0.59
E. hybrid	466	24.8	124	59.2	24.6	0.68
T. grandis	466	27.9	97	23.9	14.3	0.36
G. arborea	372	24.8	112	86.5	18.5	0.37
S. saman	372	29.4	102	112.5	12.5	0.47
A. procera	497	21.7	143	68.8	24.6	0.45
Open space	435	26.3	108	107.9	18.2	0.34
Mean	427	22.1	113	75.7	17.7	0.53
CV (%)	10.4	27.3	19.8	33.1	27.6	32.2
LSD (P=0.05)	58	2.23	27	32	1.59	0.04

Notes: [a]----Average values from 4-16 years

Various erodibility indices as estimated in soils under MPTs in agroforestry arboretum are presented in Table 11.Clay ratio was found varying from 1.60 to 3.69. The lower the ratio, the more would be clay accumulation. On the other hand, silt/clay ratio was also found varying from 0.11 to 0.42. The lower the ratio, the more would be the clay accumulation compared to that in the silt particles. It is noted that soils under the canopy of *T. grandis*, *G. maculata*, *A. auriculiformis* and *A. procera* showed more clay accumulation. Suspension percentage was found varying from 6 to 20 in the soils under MPTs. Higher the value, the more easily the soil could be eroded. This indicates that soils under the canopy of *A. auriculiformis*, *D. sissoo*, *G. arborea* would be susceptible to erosion. Clay-available water ratio underwent a variation from 0.63 to 1.63. The higher the ratio, the more would be the relative permeability of soil for water, thus reducing the possibility of soil erosion by run-off water. The dispersion and erosion ratio of soil under MPTs was found varying from 1.91 to 6.8 and 1.75 to 5.55. The low values (<10) of dispersion and erosion ratio indicated the less erosive nature of soils under MPTs.

Table 11. Effect of MPTs on soil erodibility indices[a]

MPTs	Clay ratio	Silt/clay ratio	Suspension (%)	Clay/available water ratio	Dispersion ratio	Erosion ratio
A. auriculiformis	1.74	0.11	20	1.09	1.9	1.75
M. alba	2.83	0.46	12	0.91	2.9	3.18
L. leucocephala	3.69	0.47	12	0.72	2.3	3.19
D. sissoo	2.13	0.12	14	1.10	2.6	2.36
G. maculata	1.82	0.24	7	1.53	7.0	4.57
A. indica	2.45	0.42	8	0.86	5.3	6.16
M. champaca	2.85	0.09	8	0.53	2.6	4.90
E. hybrid	2.08	0.12	10	1.14	3.4	2.94
T. grandis	1.60	0.13	10	1.43	4.4	3.07
G. arborea	3.15	0.54	14	0.85	2.5	2.94
S. saman	3.73	0.20	6	0.63	3.5	5.55
A. procera	1.75	0.27	8	1.67	6.8	4.07
Open space	1.86	0.11	13	1.18	2.9	2.45
Mean	2.44	0.25	11	1.05	3.7	3.63
CV (%)	29.5	67.4	41	37.5	43.6	35.01
LSD (P=0.05)	0.12	0.02	3	0.21	0.6	0.24

Notes: [a]----Average values from 4-16 years

Soil moisture (Table 12) was determined gravimetrically during the water deficit period (November to February) in the soil profile upto 60 cm depth when open pan evaporation (310 mm) far exceeded the rainfall (75 mm) received. As presented in Table 12, surface soil (0–15 cm) without tree cover showed 1.9 mm water whereas 2.5 mm to 8.0 mm water was noted to be present in soils under tree cover. This was due to protective cover of tree canopy reducing evaporation loss of soil moisture from the surface soil. On the other hand, moisture retention in the soil profile (60 cm depth) was maximum (103 mm) under the cover of *M. alba* but was low (70–90 mm) in soils under the cover of the other tree species. But there was 92 mm soil moisture present in soil (60 cm depth) without any tree cover. This indicated moisture extraction by trees from sub-surface soil layers.

Discussion

Growth characteristics

Agroforestry system which can assume a wide variety of forms (Nair 1984) is the most commonly suggested options for increasing the productivity of traditional farming systems (Raintree *et al*. 1985; Raintree 1987). The rural population in India is largely dependent on forest for timber, fuelwood, fodder and minor forest produce.

A. auriculiformis planted at 2500 $stems\cdot hm^{-2}$ (2 m ×2 m spacing) was a fast growing tree species. It was reported (Datta 1997) that tree survival, since their planting varied from 25% to 86.11% with *A. auriculiformis* and *E. hybrid* being the highest and lowest survival species, respectively. Datta *et al*. (2004) reported form quotient varying from 0.43 to 0.79 in MPTs. The maximum form quotient was noted in *A. procera* (0.79) and the lowest was in *T. grandis* (0.43). The high above ground biomass of *A. auriculiformis*, viz., leaf (9307 $t\cdot hm^{-2}$), twig (510 $t\cdot hm^{-2}$) and branch (639 $t\cdot hm^{-2}$) was also reported (Datta 1997) in subtropical humid climate. It indicates the suitability of *A. auriculi-*

formis as energy plantation at 2500 stems·hm^{-2}. Moreover, the fuelwood productivity on 50% pruning of tree species in alternate years was also comparatively high (5.97 Mg·hm^{-2}) from *A. auriculiformis*. The efficiency of trees as an energy source and fuelwood characteristics of some Indian trees and shrubs have been documented (Bhatt *et al*. 1990; Singh 1988) and the calorific value of *A. auriculiformis*, *A. tortilis*, *E. camaldulensis* and *E. tereticornis* varied from 17.3 to 19.3 MJ·kg^{-1}.

Table 12. Soil moisture[a] (mm) under tree cover

MPTs	Surface soil (0–7.5 cm)	Soil profile (0–60 cm)
A. auriculiformis	8.0	82.3
M. alba	6.8	102.5
L. leucocephala	6.2	89.5
D. sissoo	7.5	79.8
G. maculate	6.8	65.3
A. indica	6.5	78.3
M. champaca	5.9	75.2
E. hybrid	4.8	75.2
T. grandis	6.9	83.2
G. arborea	3.9	74.6
S. saman	5.8	72.6
A. procera	2.5	75.3
No tree	1.9	92.3
Mean	6.0	79.5
CV (%)	62.3	12.6
LSD (P=0.05)	1.5	5.87

Notes: [a]----Average values from 4-16 years

The appreciable fast growth was recorded in *A. auriculiformis*, *E. hybrid*, *G. arborea*, *A. procera, S. saman*, *M. champaca* and *T. grandis* and slow growth was noted in *L. leucocephala*, *G. maculata*, *M. alba*, *D. sissoo* and *A. indica*. *L. leucocephala* and *Gliricidia maculata* could be effectively used as live fences around the farm boundary for the supply of green leaf as manure (Dhyani *et al*. 1990) to the infertile acid soils of the tropics. Palm and Sanchez (1991) reported high N-content in the leaves of *Gliricidia* spp. (3.74%) and *Leucaena* spp. (3.94%). There is a general consensus that N- mineralization occurs if the N concentration of the plant/crop residues applied is above 2% and immobilization occurs below that concentration. The lignin and polyphenolic contents which are an effective index for N release phenomenon (Vallis *et al*. 1973; Melillo *et al*. 1982) are 5.2%–7.8% and 1.02%–2.94% in their leaves. On the contrary, leaves of *Inga edulis* contain (Palm *et al*. 1991) 16.3 % lignin and 3.43 % polyphenols. So the incorporation of *G. maculata* and *L. leucocephala* leaves as mulches and green manure may maintain soil fertility to the desired level. Moreover, the high crude protein (23.3%), high *in vitro* dry matter and organic matter digestibility (63%–65%) and low crude fiber (12.8%) could make leucaena leaf a high quality fodder (Verma *et al*. 1982; Chander *et al.* 2001).

At 16 years of age, *E. hybrid* produced the maximum timber volume (28.36 × 10^{-2}· m^3·tree^{-1}) followed by *G. arborea* (23.44 ×10^{-2}m^3·tree^{-1}), *S. saman* (22.42 ×10^{-2} m^3·tree^{-1}), *A. procera* (18.08 × 10^{-2} m^3·tree^{-1}), *M. champaca* (14.82×10^{-2}m^3·tree^{-1}) and *T. grandis* (12.56 ×10^{-2} m^3·tree^{-1}). It may be apt to mention that planting of *Eucalyptus* spp. in agricultural fields during mid 1960's could herald a sort of revolution in the economic activity related to tree planting (Pathak *et al*. 1999) in India. Considering the local demand for timber, *G. arborea*, *T. grandis*, *A. procera* and *S. saman* are largely preferred in agroforestry systems under subtropical humid climate. So multipurpose tree species planted in agroforestry systems are expected to play a major role in tropical agricultural development as the systems have low capital requirements and can produce a large array of economically useful goods for resource poor farmers.

Crop productivity

The productivity of field crops, viz., upland rice, groundnut and sesamum under MPTs showed a reduction as compared to crop yield recorded in open space. This is mainly due to competitive interaction for natural resources (light, water and nutrients) between tree components and the crop. Malik and Sharma (1990) reported 41% decline in crop productivity under the fast growing tree species of *Eucalyptus tereticornis*. There was reduction in the productivity of wheat (*Triticum* sp.) and mustard (*Brassica* sp.) upto 60%–65% under *A. nilotica* as reported by Puri and Bangarwa (1992) and Yadav *et al*. (1993). On the other hand, an increase in crop yields 5–10 m away from *Prosopis cineraria* and *Faidherbia albida* was reported in India (Shankarnarayan *et al*. 1987) and West Africa (Boffa 1999; Nair 1989). A dense canopy (Datta *et al*. 2006) in *A. auriculiformis* showing 13.2% of light transmission in open space (75,200 lx) could severely restrict the growth of field crops. On pruning, light transmission in *A. auriculiformis* was increased to 67.1% and was thereafter reduced to 10.6% after two months thus indicating high coppicing ability. Up to 0–40 cm soil depth, fine root biomass (Singh 1994) which is most actively involved in water and nutrient uptake was of high magnitude (700.44 g·m^{-2}) in *M. alba* but low in *A. indica* (80.98 g·m^{-2}) .With the formation of dense canopy, planting of shade tolerant crops could be the viable option considering the reduced light availability under MPTs (Kumar 1999). The fruit yield of pineapple (9.29 Mg·hm^{-2}) was maximum under the interspaces of *A. indica* probably due to low fine root biomass (Singh 1994). To assess the quality of pineapple grown under MPTs, similar trend of TSS and sugar content was reported (Bose *et al.* 1983; Mitra *et al.*1993). TSS/acidity ratio has been widely accepted as a measure of fruit palatability (Boyce 1960). The more the ratio, the more proportionate would be the sugar –acid blend. So the pineapple produced under the canopy of *T. grandis*, *A. indica* and *G. maculata* was of high palatability. Similar to pineapple, high turmeric productivity (4.17 Mg·hm^{-2}) was recorded under *A. indica.* The forage productivity of cowpea was comparatively high in *M. champaca* (9.94 Mg·hm^{-2}), *L .leucocephala* (8.59 Mg·hm^{-2}), *G. arborea* (7.09 Mg·hm^{-2}) and *A. indica* (7.09 Mg·hm^{-2}), thus indicating the suitability of silvi-horti or silvi-pastoral systems of agroforestry within 3–5 years after tree establishment in humid subtropical regions.

Soil properties

The finding pertaining to rise in soil pH and water holding capacity followed by a decline in exchangeable acidity in agroforestry systems after 16 years of tree establishment was corroborated by the data (Datta *et al.* 1995) recorded during the initial periods of tree growth. Similar amelioration of soil acidity in various agro-ecosystems was reported by various workers (Nye *et al*. 1964; Ramakrishna *et al*. 1981; Sanchez *et al*. 1983). Nutrient cycling from roots and foliage components might have augmented the nutrient turn over thus decreasing the soil acidity. Similar rise in nutrient availability in soils under MPTs was also

reported (Datta *et al*. 2001; Datta *et al.* 2004) probably due to substantial rise in organic carbon over the years from 4 to 16 years. Topsoil organic carbon content was found to increase significantly in Oxisols (Silva 1983) during ten years of growth of various timber species. One of the emerging areas of interest related to environments is carbon sequestration potential of agroforestry. Swamy *et al*. (2003) estimated that a six year old *G. arborea* based agrisivicultural systems in India sequestered 31.4 $Mg \cdot hm^{-2}$ carbon. Similarly, soils under *A. indica* showed the maximum SOC (28.6 $Mg \cdot hm^{-2}$) followed by *A. auriculiformis* (21.9 $Mg \cdot hm^{-2}$) and *G. arborea* (21.8 $Mg \cdot hm^{-2}$). On an average, 9.7 Pg of organic carbon was present in soils of India (Bhattacharjee *et al*. 2000).

Organic carbon may be present in the soil either in the unaltered non- mineralised form or in altered mineralized form. The part of mineralized soil organic carbon which is soluble in 0.1-N NaOH or 0.5-N Na_2CO_3 solution is called alkali soluble organic matter or humic fraction of organic matter and this fraction includes both humic acid (HA) and fulvic acid (FA). But the part of soil organic carbon which is insoluble in 0.1-N NaOH and 0.5-N Na_2CO_3 solution is placed under the humin group (Kononova 1966).The loss of the capacity of humin in dissolving in alkali is attributed not to an alteration in the nature of the components, but to the firmness of the combination with the mineral part of the soil. So humin is the portion of humic/fulvic acids strongly bound to inorganic constituents of the soils. Humin carbon is the stored organic carbon of soil organic matter and it may be mineralized to supply the energy to soil microbes so that dilute alkali soluble humic carbon will be diminished in the soil. The storing of humic carbon depends on the minerals, metal compounds and the favourable condition of humification. The comparatively high humin carbon present in soils under *A. auriculiformis*, *L. leucocephala* and *G. arborea* indicated the enhanced storage of organic carbon pool in agroforestry systems. The low humification of soil humus was recorded in soils of open space as evidenced by high E_4/E_6 ratio. The magnitude of E_4/E_6 ratio (Chen *et al.* 1977) is inversely related to the particle size or particle or molecular weight of the humic material. A low ratio indicates a large particle size, where as a high ratio, is indicative of the reverse. Datta *et al*. (2001) reported low humification in soils under shifting cultivation continuously over a period of 1-3 years.

In agroforestry systems, tree canopy and litter layer protect the soil against runoff and erosion. Soils become vulnerable to erosion loss before the development of canopy and as such, there is a desirability of establishing the cover crops in soils. Planting of pineapple under MPTs is an effective option to reduce the impact of splashing raindrops and thus the soil loss by water erosion. The erodibility characteristics as estimated indicated less erosive nature of soils and on the contrary, Datta *et al.* (1990) reported that upland soil in North East India appeared to be more susceptible to erosion, although surface soils of river basins were also observed to be erodible in nature.

Soil moisture becomes a topic of great concern in agroforestry systems due to enhanced competition for water uptake between trees and crops. It is a fact that evergreen tree species tend to use more water than the deciduous forests. Besides *Eucalyptus* spp. for high soil moisture extraction (Kallarackal *et al*. 1997), the high water use of fast growing evergreen trees can be a concern in areas with a shortage of groundwater or subsurface flows of water. Due to reduction in evaporative loss of soil moisture, soils under MPTs showed enhanced surface soil moisture. But soil profile moisture was low in soils under MPTs compared to soils of open space besides *Morus alba* showing 102.5-mm soil moisture.

Conclusion

Out of 12 multipurpose tree species (MPTs), it is observed that *A. auriculiformis*, could produce a high timber quantity of 635 $m^3 \cdot hm^{-2}$ with the tree density of 2500 hm^{-2}.The other high value timber producing tree species as identified in subtropical humid climate were *G. arborea*, *A. procera*, *S. saman*, *M. champaca* and *T. grandis*. So the demand of fuelwood and timber could be met with the help of the tree species adequate to subtropical humid climate. It can be said that field crops could be grown upto 8 years of tree planting and with gradual increase in tree canopys, silvi-hort or silvi- pastoral systems could be viable as intercrops in agroforestry systems. Organic matter build-up was appreciably high in soils of agroforestry. Control of soil erosion and moisture retentivity could be the two facets of agroforestry interventions in infertile uplands under sloppy toposequence. So multipurpose tree species planted in agroforestry systems are expected to play a major role in tropical agricultural development as the systems have low capital requirements and can produce a large array of useful goods for resource poor farmers.

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